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The Cirrus and Sub-visible Cirrus Background

by

Arnold A. Barnes, Jr.

Air Force Geophysics Laboratory
Hanscom AFB, MA

Abstract

The occurrence of cirrus particles in the upper troposphere is more common than previously reported. The presence of cirrus seems to be the rule in tropical regions with clear conditions being the exception.

Particle size distributions for both thin and opaque cirrus are presented. Two different size distributions characterize ice particles in sub-visible cirrus. The most common has a peak distribution in the 1 to 10 micron region with a rapid decrease of larger particles. The second type contains ice crystals with diameters from 100 to 2000 microns which appear to have fallen from higher levels.

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THE CIRRUS AND SUBVISIBLE CIRRUS BACKGROUND

Arnold A. Barnes, Jr.
Air Force Geophysics Laboratory
Hanscom AFB, MA

1. INTRODUCTION

The purpose of this paper is three fold: (1) to describe the different types of cirrus, (2) to show that the occurrence of cirrus clouds is much greater than previously reported, and (3) to investigate the downward transport of water and aerosols by cirrus particles from the upper mid-latitude troposphere.

Over the past decade cirrus clouds have become more important as both we and our technology have become more sensitive to environmental factors. Hypersonic reentry vehicles experience erosion due to cirrus particles in the upper troposphere. Laser systems are adversely affected by cirrus clouds. Cirrus particles reduce the efficiency of laminar flow wings. Scattering of sunlight by cirrus also inhibits solar energy collectors.

In 1974 we realized that cirrus clouds caused significant erosion of reentry nose cones. Later we studied attenuation of laser beams used in high power weapon beam systems, and the role of cirrus clouds as generating cells or seeder clouds in storm systems.

During these studies we found subvisible cirrus particles in the upper troposphere (Barnes,1980 a,b) and we documented the occurrence of both cirrus and sub-visible cirrus particles(Varley, 1978a, b,1980; Varley and Brooks, 1978; Varley and Barnes, 1979; Cohen, 1979, 1981 ; Cohen and Barnes, 1980; Varley, Cohen and Barnes, 1980). This paper summarizes our findings and extends these results to the downward flux of water and aerosols caused by the gravitational settling of cirrus particles in the troposphere.

2. BACKGROUND

Our early works with the erosion of nose cones began at Wallops Island, Virginia (Plank, 1974a,b,c; Berthel, 1976). Initially high acceleration missiles were used. They reached maximum velocity before exiting from the top of the storm. The main meteorological interest was in the middle layers of the storm with less interest in the cirrus at the top of or overlaying the storm. Since only wintertime large scale storms were used, the C-130 aircraft could usually ascend into the cirrus.

Because ground launched missiles did not simulate reentry heating and ablation, a few missiles were boosted out of the atmosphere and then accelerated back into the atmosphere at hypersonic speeds (Plank, 1977b; Cunningham, 1977). These tests were far from satisfactory to us because the reentry test region was well off of the coast and at the extreme range of the weather radars(Crane,1978).

Testing was then moved to the Kwajalein Missile Range (KMR) in the Marshall Islands. Minuteman ICBM boosters launched the reentry vehicles from Vandenberg AFB CA. Weather data in the reentry corridor and along the reentry trajectories were obtained from instrumented aircraft and from the powerful tracking radar at KMR (Barnes, Nelson, and Metcalf, 1974).

Cirrus particles near the tropopause (at 16 or 17 km) became more significant because of the higher velocity of the reentry vehicles at these heights and the increased momentum of the cirrus particles relative to the nose cones. Small particles do not survive passage through the shock wave, but large particles do strike the nose cone; they induce spalling and cause premature transition from laminar to turbulent flow. This change in the flight characteristics can cause the reentry vehicle to miss its target.

Our work in heavy weather was documented for the Wallops Island missions (Plank, 1974a, b,c; 1977a,b; Berthel, 1976) and for the KMR missions in clear, light and heavy weather (Barnes, Metcalf, and Nelson, 1974; Metcalf, Barnes, and Kraus, 1975a,b; Metcalf, Kraus and Barnes, 1975a,b,c; Barnes and Metcalf, 1975; Barnes, 1976; Dyer, Berthel and Izumi, 1981).

A review of some of the KMR test missions conducted under clear weather conditions revealed some anomalies. A preliminary investigation suggested that these anomalies were due to cirrus clouds. These missions were conducted on moonless nights to enhance visual tracking of the nose cones as they glowed white hot after reentering the earth's atmosphere at about 100km altitude. In fact the criterion for these missions was that nose cones were to be tracked optically from first glow until they reached the surface. Stars could be seen on these night reentries at Kwajalein. The stars can be seen through thin cirrus layers. This was dramatically demonstrated by photographs of some missions where the glowing nose cones lit up thin cirrus layers, temporarily obliterating the stars.

Meteorological records often showed this cirrus overcast at sunrise and sunset. Further investigations led us to conclude that there is a thin, persistent overcast of cirrus in the tropics most of the time.

Later we provided cirrus particle size distributions and densities to the Advanced Radiation Technology project of the Air Force Weapons Laboratory. These data were inputs to models of the propagation and attenuation of high energy laser weapon systems. Eight reports present the data and results from a number of C-130 flights which were conducted in New Mexico and adjoining states. Most of the data were taken in thin or opaque cirrus, but some subvisible cirrus data were obtained. These data were needed for studies of the effectiveness of high energy laser ballistic defense systems mounted in patrol aircraft. The aircraft would cruise below the cirrus and hence the laser beam would penetrate the cirrus to reach an incoming missile. Our research flights were conducted in the New Mexico area to provide climatological data for scheduled testing of the Airborne Laser Laboratory, the system's test bed.

Data obtained for these Air Force programs were used by NOAA and the Department of Energy (DOE)(Derr, 1980) to study the effects of cirrus clouds in reducing the effectiveness of solar collectors located at ground level.

Another application has been to a future aircraft which would operate in the upper troposphere (Nastrom, Holdeman and Davis,1981). This aircraft would use a laminar flow wing which would increase lift by approximately 30%. The laminar flow is held onto the wing by sucking air in through fine slits on top of the wing. The concept has been tested and flown (Hall, 1964), but the increase in lift is lost when the wing is in cloud. Test data showed occasional loss of lift when not in cloud; possibly caused by sub-visible cirrus.

The occurrence of cirrus clouds above other clouds and the seeding of lower cloud decks by large crystals (Bergeron, 1950) is important in understanding the processes occurring in storm systems and the production of precipitation. For two winter seasons we provided high cover in cirrus clouds for the investigations of storms near Seattle under the CYCLES program (Herzegh and Hobbs, 1981).

Cirrus particles may cause damage to the tiles on returning Space Shuttle flights. NASA calculations indicate that particles larger than 1mm (1000 microns) in diameter could damage the tiles.

We will attempt to define cirrus clouds and particles as they occur in the non-urban troposphere and to show how they contribute to the downward flux of both water vapor and aerosols.

3. THIN AND OPAQUE CIRRUS

We will now look at those cirrus clouds which can be detected visually. This is not a very precise definition, but it will do for now.

Cirrus clouds are generally found in that part of the troposphere where the temperature is less then -25°C. How do particles move to or form at these levels? The most dramatic way is by convective clouds such as thunderstorms. Liquid/ice water content values can exceed 3 gm/m^3 in intense storms found during summer, but concentrations at cirrus levels are usually .03 gm/m^3 or less. At mid-latitudes most cirrus is associated with cyclonic storms, the jet stream, or upper level troughs. The earth receives its maximum heating from solar radiation in the tropics and the induced convective storms play a major role in the general circulation of the earth's atmosphere. These tropical convective storms transport the water vapor from the boundary layer right up to, and in some cases beyond, the tropopause. This source of high tropospheric water vapor has been illustrated by time lapse movies from a French meteorological satellite which senses radiation at the water vapor absorbtion wavelength. These movies show tongues of water vapor surging poleward from the tropics.

At Kwajalein the frequency of severe convective storms which contained lightning or which penetrated the tropopause (as determined by radar) was small. Both visual and PMS observations indicated that cirrus was present almost all of the time at Kwajalein. Unfortunately, the airborne hygrometer did not work in the cold temperatures in the high tropical troposphere so that no measures of the relative humidity or water vapor content were obtained. The Lear 36 was limited to 14km and on almost every daylight flight we could see the thin cirrus above us. The cirrus seen above the aircraft was quickly named "cirrus evadus" or "cirrus above us".

This thin layer on almost every flight was usually seen from the surface at sunrise and sunset. I began to wonder if this thin cirrus layer persisted throughout the day and, if so, was it possible to see it at other times. The TPQ-11 radar (Paulsen, Petrocchi and Mclean, 1970) operating at a wavelength of .8cm was designed to detect cloud. Using the one at KMR, we were not able to detect this thin cirrus unless it was also obvious visually. Indeed, the human eye turned out to be a better detector since it could pick out these thicker streaks of cirrus which were not over the radar.

By blocking out the sun with the corner of a building or other object, and looking at the region near the sun, structure in the thin cirrus could be identified. Unfortunately, the structural variations in the concentration of sea salt spray in the boundry layer could also be seen at the same time. With a little training it became easy to separate the two because the low level variations moved rapidly with an east to west motion typical of the trade winds while the the cirrus moved at a slower relative motion and generally to the east or northeast, depending on the upper level winds.

Detection of this thin cirrus at night was more difficult. Even when full, the moon was not bright enough to use this technique, but by looking in the vicinity of the moon a ring could sometimes be detected. Through experience we learned to differentiate between the small ring due to the boundary layer particles and the ring caused by cirrus. If the cirrus was thick enough it could be seen by moonlight.

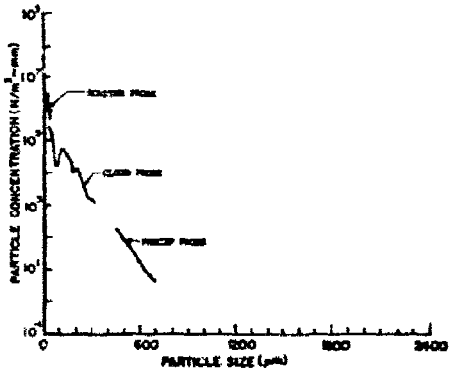
When very thin cirrus occurred on a moonless night, observation of faint stars could have been used. However, this requires a familiarity with the stars in the region.

We found that thin cirrus was present almost all the time at Kwajalein. We also observed thin cirrus over the United States when the official observers were reporting no cirrus. This higher frequency of cirrus might have an effect on available solar energy as calculated by Derr (1980).

Let us return to the question of generation of cirrus. Some particles are generated in convective storms and are lifted to cirrus levels. If the particles are heavy enough, they will settle out under gravitational action. If small (under 20 μm) they will be kept at these levels by Brownian motion and small scale turbulence.

The in-situ formation of cirrus particles from water vapor at these levels could begin either by deposition on hygroscopic aerosols, by spontaneous nucleation, or by other means. The possible mechanism of formation will not be dis-

Figure 1. Particle Size Distribution in Thin, Translucent Cirrus. (Figure 22 from Cohen and Barnes, 1980)



cussed here. We will provide data on the occurrence of cirrus particles. If there is a sufficient supply of water vapor to form cirrus, the initial size distribution seems to evolve with a peak in the distribution curve in the 1 to 10 μm region with a logarithmic decrease in the concentration with increasing size. As more particles form, the peak increases in both size and in number count. Figures 1 and 2 show typical distributions in light, opaque cirrus. For in-situ, isolated thin cirrus layers, the height of the maximum concentration is generally about 1km below the tropopause (McLean, 1957).

If enough particles form, larger particles (in excess of 1000μm) appear, and aggregation begins, causing a rapid increase of the larger particles at the expense of the middle size particles as Lo and Passarelli (1981, 1982) saw, during advecting spiral descents flown by our C-130.

Figure 3 shows a typical distribution from more dense cirrus clouds. These distributions are generally associated with wide spread storm situations where there is a large supply of water vapor and upward vertical motion to carry the water vapor to the cirrus levels. Because the winds are generally faster at higher levels than at lower levels, the cirrus shields both from thunderstorms and cyclonic storm systems move out in front of the storms while continuing to generate over the storms.

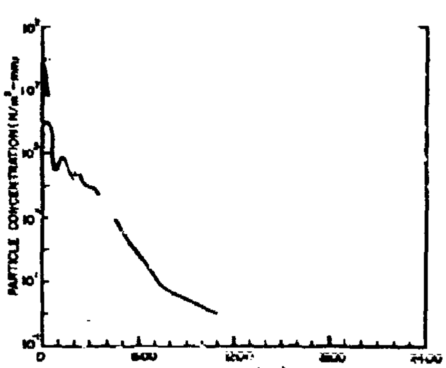


Figure 2. Particle Size Distribution in Opaque Cirrus. (Figure 13 from Cohen, 1979)

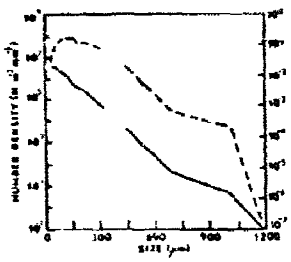


Figure 3. Size Distribution in Moderately Dense Cirrus (Figure 32 from Varley, Cohen, and Barnes, 1980)

The particles in these cirrus shields are not static, but continue to compete for available water vapor. This competition can change the characteristics of the crystals. The regular crystalian forms given by Nakaya(1954) as a function of temperature and relative humidity would be present for particles which completed this growth under static conditions, but the hybrid types would be more common close to the storm. However, after sufficient time, the dynamics of the atmosphere, with evaporation and deposition occurring, would produce cirrus which look just like cirrus produced by gentle airmass lifting.

Cirrus particle distribution flights were made in the New Mexico area in the winters of 1977-1978 and 1978-1979. The results appeared in a series of eight reports, the last by Cohen (1981). Some cirrus was associated with storms moving onto the west coast while others were associated with high level systems which were visible on satellite photographs transporting moisture from the Pacific Ocean up over western Mexico into Arizona, New Mexico, and Texas. Data were taken before we became interested in subvisible cirrus. Since the data were taken during the winter months, the C-130 could reach the cirrus level.

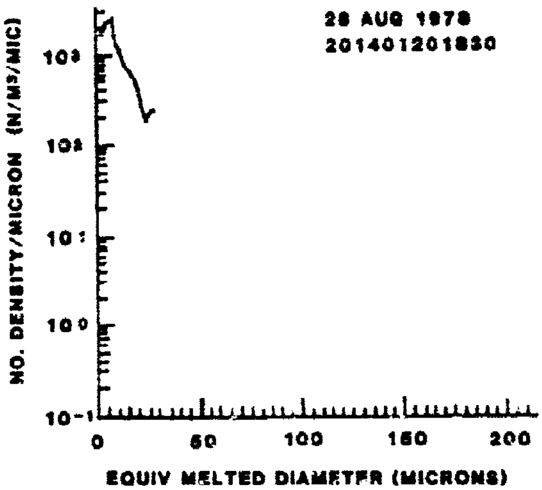
During later flights we used McIDAS (Man Computer Interactive Data Access System) at the Air Force Geophysics Laboratory to locate areas containing cirrus clouds and to obtain temperatures of the cirrus layers from satellite IR readings. Initially, the use of the McIDAS system biased our sampling toward the more opaque, denser layers which were detected by the satellites downstream from the major storm activity.

4. SUBVISIBLE CIRRUS

Sub-visible cirrus consists of cirrus particles in the atmosphere which are not dense enough to be seen. This immediately presents a problem since the same aggregation of particles may be seen at some times, but not at others. An example of thin cirrus overcasts at sunrise and sunset at Kwajalein which were not detected at night or at mid day has been cited.

Sub-visible cirrus consists of two distinct types which may exist simultaneously. The first type is the most common and consists of about 10^3 to 10^4 particles per cubic meter, a peak near 2μm and with no particles larger than 100μm. Figure 4 shows an example of an exponential fall off of particles with increasing size. Our data indicates that 70% of our flights in clear air at cirrus altitudes contain this type of background distribution. Indeed it is unusual when we are

Figure 4. Size Distribution in Type 1 Subvisible Cirrus



at cirrus altitudes and detect nothing with the PMS, ASSP scatter-probe (Barnes, 1980b).

The other type of sub-visible cirrus consists of individual large crystals, 100 to over 2000 microns in diameter, with a density of less than one particle per cubic meter. One flight showed an average of one particle every eight cubic meters. Figure 5 shows data from a flight where both types of sub-visible cirrus were present. These data were taken with a PMS ASSP and a modified PMS 2-D Precipitation Probe (Knollenberg, 1970), and the existence of the larger particles was visually verified using a snow stick (Barnes,1980b).

These large particles fall due to gravity, and in arctic regions where they may reach the ground before melting they create what are known as "diamond dust" snowfalls. Larger crystal are frequently seen to fall from higher clouds; cirrus unicus, mare's tails, is an example where the concentration is large enough to be seen. Both our observations at mid-latitudes (Barnes, 1980b) and observations by Bogan (1975) and Othake, Jayaweera and Sakurai (1978) in arctic regions provide examples where these large particles appear in clear air with no visible clouds above.

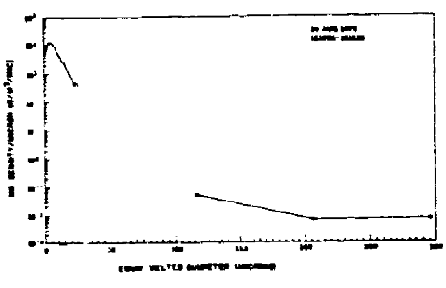


Figure 5. Example of Type 1 and Type 2 Subvisible Cirrus

Braham and Spyers-Duran (1967) and Hall and Pruppacher (1976) showed that cirrus particles of these sizes could survive falls of 2 km or more. Once these particles reach the freezing level they melt and evaporate. Because the difference between the vapor pressure over ice and over water increases with decreasing temperature, the particles have a better chance for survival at colder temperatures, on the average.

Wintertime outbreaks of cold, clear air, such as "Blue Northers" in Texas, are often said to "sparkle". This may be caused by these large sub-visible cirrus particles in the air. The affect is seen in regions of type 2 sub-visible cirrus, but not in type 1 or in the stratosphere.

5. THE ROLE OF CIRRUS IN THE TRANSPORT OF WATER

The water vapor transported poleward at upper levels precipitates at higher latitudes according to general circulation models. The larger, type 2, cirrus particles produce downward transport of water at all latitudes. Cirrus unicus clouds are visual examples of this downward tranzport.

If we take a world wide density of type 2 particles at one every 8 cubic meters (Barnes, 1980b), an average diameter of 200 μm, density of 0.5 gm/cm^3, fall speed of 1 m/s and a fall distance of 2km (Braham and Spyers-Durand, 1967; Hall and Pruppacher, 1976), then for each square meter, one particle reaches the bottom each 8 seconds. The amount of mass crossing a square meter every 8 seconds is:

$$\frac{4}{3}\pi r^3 \rho = \frac{4}{3}\pi\, 0.5\, \frac{gm}{cm^3}\,(10^{-2}cm)^3 = \frac{2\pi}{3}\, 10^{-6}\, gm .$$

The flux per unit area for each second is:

$$\frac{1}{8s}\,\frac{2\pi}{3}\,10^{-6}\,\frac{gm}{m^2} = 2.6\times10^{-7} gm\, m^{-2}\, s^{-1}.$$

The surface of the earth is $4\pi R^2 = 4\pi(6.378\times10^6 m)^2 \approx 511\times10^{12}\, m^2$; the total flux is $2.6\times10^{-7} gm\, m^{-2}s^{-1}\times511\times10^{12} m^2 = 1.33\times10^8\, gm/s^1 = 1.33\times10^5 kg\, s^{-1}$. For a full year this is $1.33\times10^5 kg\, s^{-1}\times3.15\times10^7\, s/yr = 4.19\times10^{12} kg/yr$. Beers (1945) gives the world annual rainfall as 396,000 km^3/yr or 3.96×10^{20}kg/yr which shows that, on a world wide basis, this downward flux of large cirrus particles is an infinitesimal contribution to the hydrological cycle.

If we calculate the depth of type 2 snowfall in artic regions with a constant flux of 200 μm particles, one per 8 cubic meter falling at 1m/s, we get $\frac{4\pi}{3}\left(\frac{200\mu m}{2}\right)^3 \frac{1}{8m^3}\,\frac{1m}{s}\,3.15\times10^7\,\frac{s}{yr} = \frac{16\mu m}{yr}$.

This does not agree with observations of diamond dust snowfalls in arctic regions where accumulations of cm/yr are observed. Such observations indicate a 10^3 or 10^4 increase in concentration to around 10^2 or 10^3 particles/m^3. Concentrations of 200 μm and larger particles usually produce opaque cirrus. The reduction of visibility in opaque cirrus may be due to the larger number of type 1 ice particles in the 1 to 10 μm range usually found in opaque clouds along with the ice crystals over 200 μm in diameter.

A 10^4 increase in the number of particles would give 16cm/yr thus accounting for a large part of the annual precipitation in arctic regions. In warmer climates these particles melt and evaporate before reaching the ground.

Cirrus particles falling from above into supercooled clouds act as seeders, converting the supercooled drops to ice which then grow rapidly leading to precipitation (Bergeron, 1950). This trigger mechanism is important in the precipitation processes in mid-latitudes, but it is doubtful that concentrations of type 2 sub-visible cirrus of one or two particles/m^3 can seed the lower clouds. Heavier concentrations of type 2 cirrus have been observed by K band radar (Paulsen, Petrocchi and McLean, 1970). These appear similar to visual cirrus unicus and seem to emanate from generating cells. Using a TPQ-11, Hobbs, et al (1981) observed such a seeding and an enhancement of precipitation falling from the supercooled cloud although the precipitation was not recorded on the ground.

6. DOWNWARD TRANSPORT OF AEROSOLS BY CIRRUS

The gravitational settling of the type 2 particles is a source of downward transport of aerosols. Temperatures at the upper levels are colder, so more ice nuclei (IN) are activated. In the presence of sufficient water vapor, ice crystals grow rapidly and begin to fall. The particles carry the IN to lower levels, and also sweep up other aerosols as they descend. If we assume that the type 2 crystals form on IN with diameters of .2 m and density of 2 gm/cm^3, then the downward flux would be about 10^{-5}kg/yr. Each crystal would sweep up 10^5 aerosols, so the scavenging process would be the more important factor in the downward aerosol transport.

7. SUMMARY

Observations of cirrus in the tropics and at mid-latitudes have shown that the occurrence of cirrus ice particles in the atmosphere is more prevalent than reported by ground observers.

Sub-visible cirrus observed from aircraft consist of two types. Type 1 is the background of small ice particles with a peak in the size distribution at about 1 μm and a rapid exponential decrease for larger size particles. Type 1 is found at cirrus levels on most flights. The second type of sub-visible cirrus consists of large ice crystals with diameters greater than 100 μm, some being larger than 2000μm. Type 2 crystals fall through the atmosphere and may or may not be found in conjunction with type 1 sub-visible cirrus.

Opaque and thick cirrus clouds usually have a peak in the size distribution between 10 and 20 μm with an exponential decrease at larger sizes.

The downward flux of water and aerosols by subvisible type 2 cirrus is insignificant except in arctic regions where diamond dust snowfalls occur. Concentrations of type 2 cirrus falling from generating cells in large scale storm systems play a significant role in triggering precipitation in lower level, supercooled clouds.

8. *REFERENCES*

Barnes, A.A., 1976: Operations Plan for the REMP-related Elements for Mission A.N.T.-1. Unpublished AFGL report, dated 23 January 1976.

Barnes, A.A., 1980a: Ice Particles in Clear Air. Communications a la VIIIeme Conference Internaionale sur la Physique des Nuages, Vol I, Clermont Ferrand, France, 15-19 July 1980, 189-190. AFGL-TR-81-0009. AD 094444.

Barnes, A.A., 1980b: Observations of Ice Particles in Clear Air. J. Rech. Atmos., 14, No. 3-4, 311-315, AFGL-TR-81-0347. AD A108914.

Barnes, A.A., and J.I. Metcalf, 1975: ALCOR High Altitude Weather-Scans, AFCRL/A.N.T. Report No 1, Air Force Surveys in Geophysics, No.335, AFCRL-TR-75-0645. AD B011588L.

Barnes, A.A., J.I. Metcalf and L.D. Nelson, 1974: Aircraft and Radar Weather Data Analysis for PVM-5, AFCRL/Minuteman Report No. 1. Air Air Force Surveys in Geophysics, No. 297. AFCRL-TR-74-0627. AD B004290L

Barnes, A.A., L.D. Nelson and J.I. Metcalf, 1974: Weather Documentation at Kwajalein Missile Range, Air Force Surveys in Geophysics, No. 292, AFCRL-TR-74-0430. AD A000925.

Beers, N.R., 1945: Evaporation and Distribution of Water Vapor in the Atmosphere. Handbook of Meteorology, F.A. Berry, E. Bolley and N.R. Beers, Eds., McGraw-Hill Book Co., Inc., New York, 737-745.

Bergeron, T., 1950: Über der Mechanssims der Ausiebigen Nederschlage. Berichte des Deutchen Wetterdienstes, 12, 225-232.

Berthel, R.O., 1976: A Climatology of Selected Storms for Wallops Island, Virginia, 1971-1975, AFGL/SAMS Report No. 4. Environmental Research Papers, No. 563. AFGL-TR-76-0118. AD A029354.

Braham, R.R., and P. Spyres-Durand, 1967: Survival of Cirrus Crystals in Clear Air. J. Appl. Meteor., 6, 1053-1061.

Cohen, I.D., 1979: Cirrus Particle Distribution Study, Part 5. Air Force Surveys in Geophysics, No. 414. AFGL-TR-79-0155. AD A077361.

Cohen, I.D., 1981: Cirrus Particle Distribution Study, Part 8. Air Force Surveys in Geophysics, No. 437. AFGL-TR-81-0316.

Cohen, I.D., and A.A. Barnes, 1980: Cirrus Particle Distribution Study, Part 6. Air Force Surveys in Geophysics, No. 430. AFGL-TR-80-0261. AD A096772.

Crane, R.K., 1978: Evaluation of uncertainties in the estimation of hydrometeor mass concentrations using SPANDAR data and aircraft measurements. Scientific Report No. 1, ERT. AFGL-TR-78-0118. AD A059223.

Cunningham, R.M., 1977: MSV-2 Test, 20 March 1977. Unpublished AFGL report dated 5 August 1977.

Derr, V.E., 1980: Attenuation of Solar Energy by High, Thin Clouds. Atmospheric Environment, 14, 719-729.

Dyer, R.M., R.O. Berthel and Y. Izumi, 1981: Techniques for Measuring Liquid Water Content Along a Trajectory. Environmental Research Papers, No. 733. AFGL-TR-81-0082. AD A102922.

Hall, G.R., 1964: On the mechanics of transition produced by particles passing through an initially laminar boundary layer and the estimated effect on the LFC performance of the X-21 aircraft. Unpublished Northrop Aircraft technical report, October 1964.

Hall, W.D., and H.R. Pruppacher, 1976: The Survival of Ice Particles Falling From Cirrus Clouds in Subsaturated Air. J. Atmos. Sci., 33, 1995-2006.

Herzegh, P.H., and P.V. Hobbs, 1981: The Mesoscale and Microscale Structure and Organization of clouds and Precipitation in Midlatitude Cyclones.IV. Vertical Air Motions and Microphysical Structures of Prefrontal Surge Clouds and Cold Frontal Clouds. J. Atmos. Sci., 38, 1771-1784.

Hobbs, P.V., et al, 1981: Radar Detection of Cloud Seeding Effects. Science, 213, 1250-1252.

Hogan, A.W., 1975: Summer Ice Crystal Precipitation at the South Pole. J. Appl. Meteor., 14, No 2. 246-249.

Knollenberg, R., 1970: The Optical Array. an Alternative to Scattering, or Extinction for Airborne Particle Size Determination. J. Appl. Meteor., 9,86-103

Lo, K.K., and R.E. Passarelli, 1981: Height Evolution of Snow-Size Distributions. Preprints of the 20th Conference on Radar Meteorology, Boston, MA, 30 Nov.- 3 Dec. 1981, 397-401.

Lo, K.K., and R.E. Passarelli, 1982: The Growth of Snow In Winter Storms: An Airborne Observational Study. J. Appl. Meteor. submitted for publication.

McLean, G.S., 1957: Cloud Distributions in the Vicinity of the Jet Stream. Bull. Amer. Meteor. Soc., 38, 579-583.

Metcalf, J.I., A.A. Barnes and M.J. Kraus, 1975a: Final Report of PVM-4 and PVM-3 Weather Documentation, AFCRL/Minuteman Report No. 2. Air Force Surveys in Geophysics, No. 300. AFCRL-TR-75-0097. AD B004427.

Metcalf, J.I., A.A. Barnes and M.J. Kraus, 1975b: Final Report of STM-8W Weather Documentation, AFCRL/Minuteman Report No. 3. Air Force Surveys in Geophysics, No. 308. AFCRL-TR-75-0207. AD B006666L.

Metcalf, J.I., M.J. Kraus and A.A. Barnes, 1975a: Final Report of PVM-5 Weather Documentation, AFCRL/Minuteman Report No. 4. Air Force Surveys in Geophysics, No. 320. AFCRL-TR-75-0302. AD B006667L.

Metcalf, J.I., M.J. Kraus and A.A. Barnes, 1975b: Final Report of OT-45, PVM-8, and RVTO Weather Documentation, AFCRL/Minuteman Report No. 5. Air Force Surveys in Geophysics, No. 314. AFCRL-TR-75-0388. AD B011352L.

Metcalf, J.I., M.J. Kraus and A.A. Barnes, 1975c: Final Report of PVM-6 and PVM-7 Weather Documentation, AFCRL/Minuteman Report No. 6. Air Force Surveys in Geophysics, No. 323. AFCRL-TR-75-0481 AD B011353L

Nakaya, U., 1954: Snow Crystals, Natural and Artificial. Harvard University Press, Cambridge, 510p.

Nastrom, G.D., J.D. Holdeman and R.E. Davis, 1981: Cloud-Encounter and Particle-Concentration Variables. From GASP Data. NASA Technical Paper 1886, December, 1981, 244p.

Othake, T., K.O.L.F. Jayaweera and K. Sakurai,1978: Formation Mechanism of Ice Crystals in the Cloudless Atmosphere. Proc. Conf. Cloud Physics and Atmos.Electricity, 31 July-4 August 1978, 122-125.

Paulsen, W.H., P.J. Petrocchi and G.S. McLean, 1971: Operational Utilization of the AN-TPQ-11 Cloud Detection Radar. Instrumentation Papers, No. 116, AFCRL-TR-70-0335. AD 709364.

Plank, V.G., 1974a: A Summary of the Radar Equations and Measurement Techniques Used in the SAMS Rain Erosion Program at Wallops Island, Virginia, AFCRL/SAMS Report No. 1. Special Reports, No. 172. AFCRL-TR-74-0053. AD A778095.

Plank, V.G., 1974b: Hydrometeor Parameters Determined From the Radar Data of the SAMS Rain Erosion Program.AFCRL/SAMS Report No. 2. Environmental Research Papers, No. 477. AFCRL-TR-74-0249. ADA786454

Plank, V.G., 1974c: Liquid-Water-Content and Hydrometeor Size-Distribution Information for the SAMS Missile Flights of the 1971-72 Season at Wallops Island, Virginia, AFCRL/SAMS Report No. 3. Special Reports, No. 178. AFCRL-TR-74-0296. AD A002370.

Plank, V.G., 1977a: Hydrometeor Data and Analytical-Theoretical Investigations Pertaining to the SAMS Rain Erosion Program of the 1972-73 Season at Wallops Island, Virginia. Environmental Research Papers, No. 603, AFGL-TR-77-0149. AD A051192.

Plank, V.G., 1977b: MSV Test, 15 December 1976. Unpublished AFGL report dated 25 February 1977.

Varley, D.J., 1978a: Cirrus Particle Distribution Study, Part 1. Air Force Surveys in Geophysics, No. 394. AFGL-TR-78-0192. AD A061485.

Varley, D.J., 1978b: Cirrus Particle Distribution Study, Part 3. Air Force Surveys in Geophysics, No. 404. AFGL-TR-78-0305. AD 066975.

Varley, D.J., 1980: Microphysical Properties of Large Scale Cloud Systems, 1-3 March 1978. Environmental Research Papers, No. 690. AFGL-TR-80-0002. AD A083140.

Varley, D.J., and A.A. Barnes, 1979: Cirrus Particle Distribution Study, Part 4. Air Force Surveys in Geophysics, No. 413. AFGL-TR-79-0134. AD A074763.

Varley, D.J., and D.M. Brooks, 1978: Cirrus Particle Distribution Study, Part 2. Air Force Surveys in Geophysics, No. 399. AFGL-TR-78-0248. AD A063807.

Varley, D.J., I.D. Cohen and A.A. Barnes, 1980: Cirrus Particle Distribution Study, Part 7. Air Force Surveys in Geophysics, No. 433. AD A100269

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The occurrence of cirrus particles in the upper troposphere is more common than previously reported. The presence of cirrus seems to be the rule in tropical regions with clear conditions being the exception.

Particle size distributions for both thin and opaque cirrus are presented. Two different size distributions characterize ice particles in sub-visible cirrus. The most common has a peak distribution in the 1 to 10 micron region with a rapid decrease of larger particles. The second type contains ice crystals with diameters from 100 to 2000 microns which appear to have fallen from higher levels.

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